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THE PREVENTION OF STRAY VOLTAGE IN ELECTRO-EXPLOSIVE CIRCUITS

by

Glenn R. Linsenmayer

1/Lt. USAF

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Project No. 5793

ABSTRACT

A number of incidents have occurred involving the inadvertent actuation of electro-explosive devices, in various armament systems, by various sources of stray voltage. This report summarizes methods of circuit design and testing which may be used to prevent such actuations.

PUBLICATION REVIEW

This report has been reviewed and is approved.

John J. Dishuck

JOHN J. DISHUCK
Colonel USAF
Deputy Chief of Staff for Operations

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1. INTRODUCTION.

Many weapon systems now in use or being developed make use of electro-explosive devices (EED's) as a source of energy to perform vital functions. Examples of such uses are the use of explosive cartridges to power weapon release mechanisms and the use of pyrotechnic devices to ignite solid propellant rockets and missiles. These devices make little or no distinction between an intentionally applied firing signal and electrical contamination (unwanted voltage which may be present in the firing circuits and which may inadvertently cause firing of the EED). The consequences of such an inadvertent firing may be serious and far-reaching in the present political state of the world. By proper circuit design and testing, the chances of inadvertent actuation may be made negligible. It is of extreme importance that firing circuits for EED's be carefully designed with the possibility of inadvertent actuation always being thoroughly considered. In the following pages, a brief summary is made of the problem of stray voltage (or energy) and of steps which may be taken to reduce this problem. For more complete information, attention is drawn to the references.

2. BRIDGE WIRE DEVICES.

The type of explosive device most often used in aircraft equipment is fired by means of a fine bridge wire imbedded in an explosive primer. Electric current of sufficient amperage passing through the bridge wire heats the primer until the primer ignites, in turn igniting other explosives in the explosive device. Some of the heat generated before ignition is lost to the environment; the amount lost before ignition depends on the rate of heat input. Thus the energy required for ignition depends on the power input to the EED.

a. There is a minimum energy required to initiate an explosive device; this energy is roughly proportional to the volume of the bridge wire. It is approximately the energy required to raise the bridge wire to the ignition temperature (this temperature varies somewhat with wire diameter), and must be delivered in a time period short enough to make any heat dissipated negligible.

b. There is a minimum power required for initiation. Below

this power, heat dissipated will not allow a temperature great enough for initiation to be reached, and an infinite amount of energy will not cause initiation.

c. Between these extremes, the energy required for initiation depends upon its wave form. The faster energy is delivered, the less is dissipated before ignition, and hence the smaller the amount of energy required for initiation.

Because of mechanical considerations, the bridge wire must be relatively short and heavy, and hence of low resistance. Therefore, a bridge wire EED is a low-voltage, high-current device. Typical values are 5 amperes firing current and 1 ohm resistance for relatively nonsensitive devices.

3. CARBON FILM DEVICES AND CONDUCTIVE MIX DEVICES.

Carbon film devices dissipate electrical energy in a film of carbon deposited between two electrodes. Conductive mix devices dissipate electrical energy in a conductive explosive mix joining two electrodes. In each case the dissipated energy ignites the primer explosive. These devices are generally high resistance devices (as high as 10,000 ohms) of very high sensitivity, and are not generally used except in circuits where limited firing energy is available.

4. INADVERTENT ACTUATION.

A number of instances of the inadvertent actuation of electrically initiated explosive devices have been reported. The causes of these actuations include circuit miswirings, circuit failures, electrical transients, and induced radio frequency (RF) energy. A partial list of inadvertent actuations due to some form of stray voltage is included in the appendix.

Data available are insufficient to permit an accurate estimation of the probability of occurrence of inadvertent actuations. A very rough guess at this probability may be made by examining data on actual firings of the 2.75" folding fin aerial rocket (FFAR). From 2.75" FFAR firing reports it was determined that four incidents occurred in an estimated 18,168 opportunities, yielding a probability of 0.00022. Of a total of 45 reported incidents, 14 were due to some form of stray voltage (usually resulting from faulty

wiring). This yields a probability of inadvertent firings caused by stray voltage of the order of 10^{-4}, for the 2.75" FFAR. The firing circuit used with the 2.75" FFAR at the time of the reported incidents was a relatively unsafe circuit.

A number of steps will contribute to the prevention of dangerous conditions caused by activation of an EED by stray voltage. Some of these steps are the following:

a. Prevent stray voltage from reaching the EED.

b. Mechanically lock the explosive system so that even if the EED's are fired a dangerous condition cannot occur.

c. Decrease the response of the EED's to stray voltage.

d. Check the EED firing circuit for stray voltages.

5. PREVENTING STRAY VOLTAGE.

In most, if not all cases, EED's can be protected from stray voltage by proper circuit design. Figure 1 shows principles of circuit design which will minimize the danger of stray voltage.

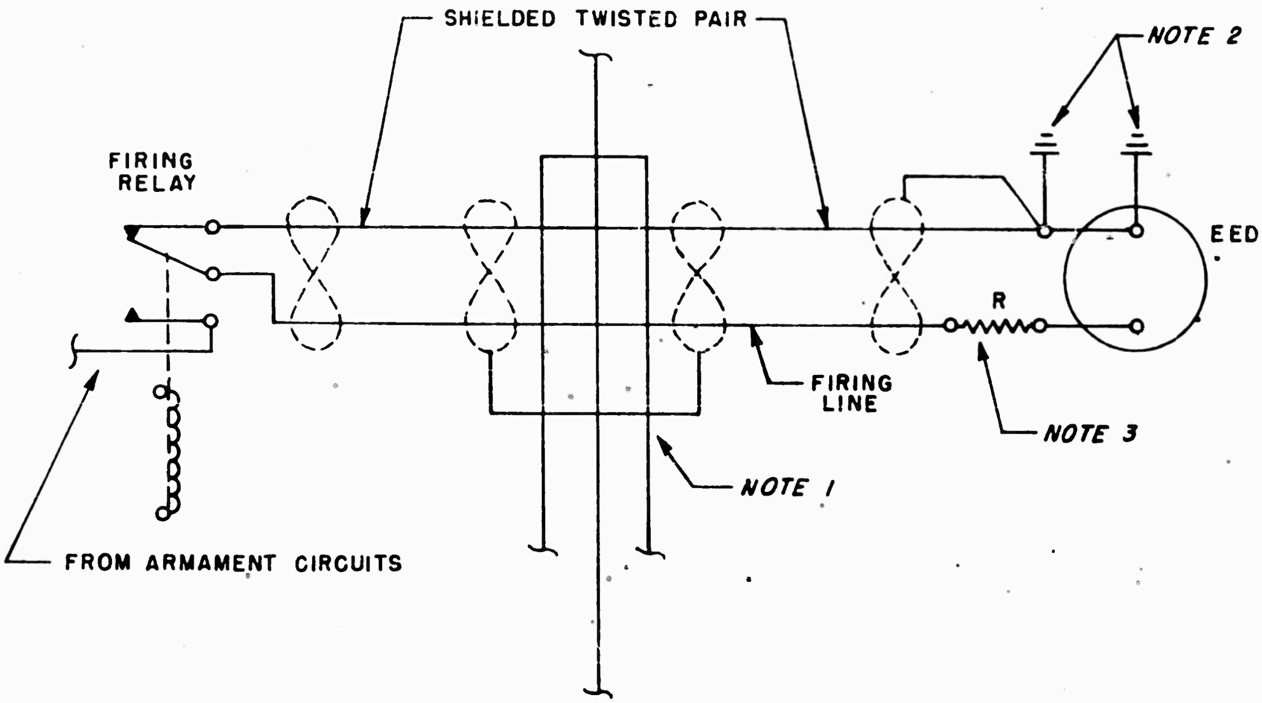


Figure 1

NOTES:

1. Connectors and terminal boards should be used only if absolutely necessary. If connectors or terminal boards are used, the firing line should be physically isolated from power-carrying pins as much as possible. It is preferable that connectors and terminal boards used to carry EED firing circuits not be used for other circuits. These precautions will help prevent stray voltage caused by shorts or low insulation resistance from other circuits, or by miswiring which may occur during maintenance.

2. All grounds should be physically as close together as possible. The maximum distributed resistance Rmax between grounds, and between R and ground through the firing relay, is given approximately by:

$$R_{max} = \frac{(2 \times I_{no\ fire})}{(I_{max})} (R + R_{EED}) \quad \text{where}$$

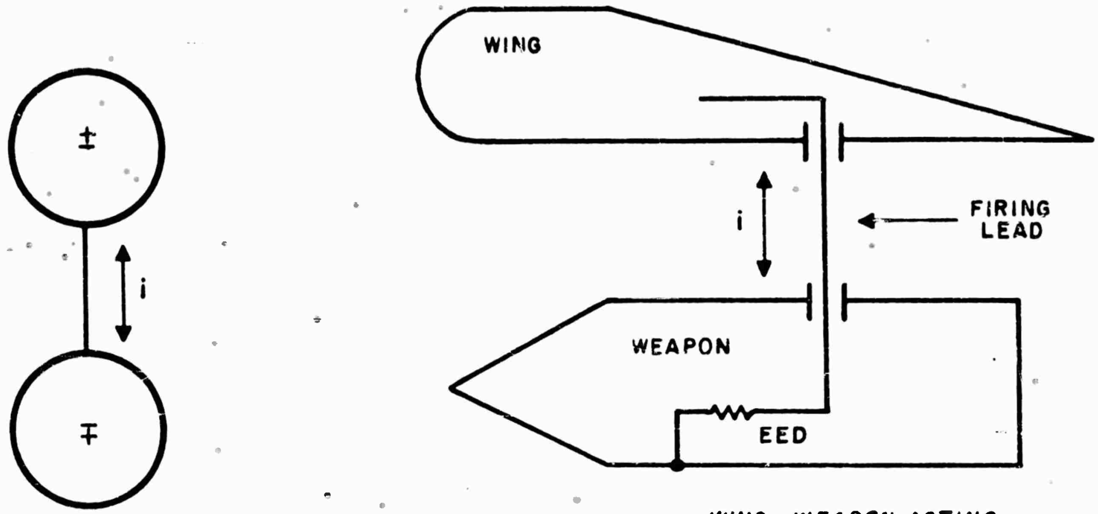
$I_{no\ fire}$ is the manufacturer's stated no fire current, I_{max} is the maximum current which may be expected to flow momentarily through the distributed resistance between grounds as a result of ground currents (caused possibly by shorting of nearby power lines to ground) or through the distributed resistance between R and ground (through the normally closed firing relay contacts) as a result of a direct short from nearby circuits to the firing line. A typical value of I_{max} would be 500 amperes. R_{EED} is the resistance of the electro-explosive device. This limit on R_{max} is to prevent EED ignition in the event of a direct short from 28 volts d.c. or in the event of heavy ground currents. The short through the firing relay will also eliminate stray voltage caused by low insulation resistance from nearby circuits and by static electricity.

3. R should limit the firing current to the manufacturer's recommended firing current, and should not mechanically support the firing lead. If desired, R may be placed between the firing relay and the armament circuits, or in the armament circuits, but this may decrease the value of R_{max}.

Location of wiring should be such as to minimize the possibility of shorts, miswiring, or stray voltage. Wire runs should be as short as possible.

The circuit shown in figure 1 does not completely protect against RF voltages in extreme RF fields. EED's have been fired by the Navy in close proximity to vertical antennas operating at about 4 to 8 mc.

These occurrences are apparently due to the aircraft wing, the umbilical, and the weapon acting as a receiving dipole, as shown in figure 2. (Reference 5.)



RECEIVING DIPOLE

WING-WEAPON ACTING AS RECEIVING DIPOLE

Figure 2

This circuit can cause dangerous RF currents (when in a strong RF field from a vertical antenna) in two ways:

a. If the firing lead is connected to the wing (directly, inductively, or capacitively) before grounds in the umbilical are connected, the wing, umbilical, and weapon act as a dipole with all of the RF current i flowing through the EED.

b. If a person handles the umbilical before connecting it (and this is difficult to avoid), the weapon and the earth act as a dipole, passing RF current through the person and the EED. Direct contact with the firing lead is unnecessary; capacitive coupling may be sufficient to ignite the EED.

Steps which may be taken to diminish this problem and other possible RF problems are as follows.

a. Use EED's with two leads, and move the ground (note 2, figure 1) to the firing relay within the wing.

b. Move the firing relay to within the weapon.

c. Use EED's which are relatively immune to RF energy.

d. Use RF filters in series with the firing lead.

e. Take precautions to keep aircraft out of extreme RF fields, particularly near fields from vertical antennas.

f. Take precautions to insure that umbilical grounds are always established between the weapon and the wing before firing leads are handled.

A great amount of information on the problem of RF actuation of EED's may be obtained from publications published in connection with the Navy's HERO program.

6. MECHANICALLY LOCKING THE EXPLOSIVE SYSTEM.

The USAF Nuclear Weapons System Safety Board generally requires a reversible mechanical lock on special weapons electro-explosive release mechanisms such that, if the lock is locked, release will be prevented even in the event of EED ignition. This lock, providing it doesn't fail, is a good fix for the stray voltage problem from the standpoint of safety, and permits less stringent circuit design. In one recent instance, however, inadvertent release of a trainer occurred in spite of a mechanical lock on the aircraft.

7. DECREASING RESPONSE OF THE EED'S TO STRAY VOLTAGE.

Two methods exist for decreasing the response of EED's to stray voltage: make the EED less sensitive to all voltage; and make the EED less sensitive to stray voltage only.

A limit to the maximum current which a bridgewire EED can be designed to tolerate without firing (no-fire current) results from the fact that the current required for rapid, reliable firing (recommended firing current) is generally five or more times the no-fire current, and the firing circuit must be able to deliver this current.

AFSWC and the Navy are each carrying on a program to develop radio frequency insensitive EED's. Preliminary results are promising, but final success is not assured. It appears difficult to prevent the initiation of explosive devices by RF energy over a very wide bandwidth. At the present time, no practical EED exists which is RF insensitive from broadcast

bands through UHF.

8. CHECKING CIRCUITS FOR STRAY VOLTAGE.

When considering stray voltage testing, two ideas conflict: the idea of simulating the impedence of an electro-explosive device, thus measuring only "dangerous" stray voltage; and the idea of using a tester capable of measuring low insulation resistance (1 to 5 megohms) from a power source, such as 28 volts d. c. The conflict arises because an instrument having sufficient current sensitivity to measure low insulation resistance and sufficient voltage sensitivity to measure low-impedence, low-voltage, stray voltage will detect a low voltage medium impedence stray voltage source (such as may be due to electrolytic action) which would be quite safe to an EED.

To circumvent this conflict, two tests should be made; a "stray voltage" test, and an "insulation resistance" test. The stray voltage test will use a tester with an impedence equal to that of an EED. The insulation resistance will use a tester having high current sensitivity but low voltage sensitivity; this will permit measurement of low insulation resistance without false indications of danger caused by low energy sources such as electrochemical action.

AFSWC is presently developing testers and/or test methods according to the above principle. As an interim measure, a PSM-6 multimeter or equivalent can be used to test circuits using the MK 1 Mod 3, MK 2 Mod 1, ARD 446-1 bomb ejection cartridges, the MA 1 rocket engine igniter, or the motor ignition battery used in the MB-1 rocket, by setting the meter on the ACV 1KΩ/V function, 0.5 range. No deflection of the pointer in either direction should exist during this test. This setting provides a meter input resistance of 500 ohms. A voltage of 0.005 volt will cause a noticeable deflection of the pointer. This will permit the detection of about 11.5 megohms from 115 volts a. c. Since the a. c. function on the PSM-6 will indicate d. c., this test will also detect insulation resistance from 28 volts d. c. of about 2.8 megohms. The meter resistance is sufficiently low that no false indications of danger should be caused by negligible, low-voltage, medium-impedence, stray voltage sources (such as sources due to electrochemical action).

A stray voltage test should be made for personnel protection immediately before the connection of an EED. In addition, tests should be periodically made for insulation resistance and for stray voltage during operation of aircraft equipment.

APPENDIX

DATE	PLACE	AIRCRAFT/ARMAMENT	EVENT	CAUSE
6 Sep 57	George AFB	F-102A/GAR-2	2 missiles fired	Undetermined
1 Nov 57	Truax AFB	F-102A/GAR-2	2 missiles fired	Undetermined
19 Feb 58	Suffolk Co, AFB	F-102A	6 missiles fired	Believed to be induced transients or RF
2 May 58	Goosebay, Laborador	F-89J	1 missile fired	Believed to be ground currents resulting from dirty umbilical connections
8 Sep 55	Inyokern, California	F-86D/2.75"FFAR	Premature missile firing	Wiring change bypassed rocket package downlock switch
8 Mar 56	Tyndall AFB	F-86D/2.75"FFAR	Rocket fired when pod retracted	Rocket pod downlock switch wires crossed
28 Jan 57	McGhee-Tyson AFB	F-86D or L/2.75"FFAR	Explosion occurred when rudder trim returned to neutral (preflight check)	Misrouted wire
3 Jul 56	Yuma, Arizona	F-89H/2.75"FFAR	3 rockets fired	Faulty camera wire installation
5 Nov 56	Selfridge AFB	F-86L/2.75"FFAR	1 rocket fired	Faulty aerial gunnery camera installation
27 Jun 56	Charleston AFB	F-86D/2.75"FFAR	3 rockets fired	Autopilot system wired incorrectly into armament system

2 Aug 56	Elmendorf AFB	F-89D/2,75"FFAR	Left pod fired all rockets	Incorrect wiring installation
20 Apr 56	Oxnard AFB	F-89D/2.75"FFAR	1 rocket fired	Stray voltage when APU a.c. connected
6 Jan 57	McGuire AFB	F-86/2.75"FFAR	1 rocket fired after stray voltage check	Short caused by loose pieces of solder
9 Oct 56	New Castle AFB	F-94C/2.75"FFAR	4 rockets fired	Stray voltage suspected
7 Aug 56	Tyndall AFB	F-86D/2.75"FFAR	2 rockets fired	Stray voltage suspected
20 Sep 56	Otis AFB	F-94C/2.75"FFAR	1 rocket fired	Short
20 Oct 56	Perrin AFB	F-86D/2.75"FFAR	Rocket pod jettisoned	Faulty switch and short
18 Feb 54	O'hare International	F-86D/2.75"FFAR	1 rocket fired	Faulty wiring
Unknown	Unknown	F-86D/2.75"FFAR	1 rocket fired	Stray voltage suspected
29 Apr 58	Luke AFB	F-84F	Pylon squibs detonated	Damaged plug caused short
Jan 58	Dyess AFB	B-47E	Wing tank explosive detonated bolt	Unknown
Dec 57	Lake Charles AFB	B-47E	Wing tank explosive bolt detonated or failed (Primer charge had not been fired)	Unknown
Dec 57	Lake Charles AFB	B-47E	Wing tank explosive bolt detonated or failed (Primer charge had not been fired)	Unknown
Oct 57	Lake Charles AFB	B-47E		

4 July 58	Myrtle Beach AFB	F-100D ARD 446-1 Cartridge	Bomb ejector cartridge fired (stray voltage check negative)	Unknown
Unknown	Unknown	F-86A	Fuel drop tanks, jettisoned during flight	Moisture
Unknown	Unknown	F-86A	Fuel drop tanks jettisoned on ground	Moisture shorted switch
23 Aug 57	Williams AFB	F-86F, MK2, Mod 1 (4 each)	Fuel tanks jettisoned	Moisture assumed to be cause
13 Apr 59	Oxnard AFB	F-89J	Explosive bolt detonated	Unknown
Unknown	Eglin AFB	F-104/Sidewinder Pylon	Cartridge exploded	Short caused by moisture
Unknown	Eglin AFB	F-100D	"Incident"	Aerodynamic heating
Unknown	Picatinny Arsenal	Loki Missile	Warhead exploded	Heat (600°F) attained after 5-6 seconds of flight
Unknown	Unknown	B-52	Wing tanks jettisoned	Heat from exhaust of aircraft ahead, while lined up for takeoff
Unknown	Unknown	B-52	Wing tanks jettisoned	Radio station
Unknown	Unknown	B-57	Canopy	Radar
Unknown	Unknown	Unknown	Parachute mine in flight	Radar (duplication proved)
On board Carrier			2.75"FFAR and SCAR rockets fired	Radar (numerous cases test proven)

Unknown	Unknown	Terrier	"Incident"	Radar
Unknown	Unknown		11.75 AR Motor fired during sled test of Bomarc warhead	RF from mobile transmitter
Unknown	USS Ashland		Liki rocket fired	Probably radar

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A number of incidents have occurred involving the inadvertent actuation of electro-explosive devices, in various armament systems, by various sources of stray voltage. This report summarizes methods of circuit design and testing which may be used to prevent such actuations.

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3. Electric discharges
4. Electrical conductivity
5. Explosive actuators
6. Fuzes
7. Missile arming and fuzing
8. Premature probability
9. Radio-Frequency
10. Rockets

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II. Air Force Special Weapons Center, Kirtland AFB, N Mex
III. Project 5793

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THE PREVENTION OF STRAY VOLTAGE IN ELECTRO-EXPLOSIVE CIRCUITS, by Glenn R. Linsenmayer. July 1961. 22 p. incl. illus. (Proj. 5793) (AFSWC-TN-61-24) Unclassified report

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